TARGET ACQUISITION WEAPONS SOFTWARE (TAWS) IMPROVEMENTS FOR OVER-WATER TARGETS

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ABSTRACT

The Target Acquisition Weapons Software (TAWS) is a weather impact tactical decision aid. TAWS was originally developed by the U.S. Air Force, but has been significantly upgraded and adapted to meet Army, Navy-Marine, and Coast Guard applications. This paper discusses improving TAWS predictions for naval applications by adding the wake effects to boat and ship targets. TAWS could not accurately model moving water targets prior to this improvement because wake effects were not modeled. An empirically based computational approach is taken to accommodate the runtime constraints of an operational mission planning system. While TAWS only requires a computed wake correction for target-background temperature contrast and apparent area, the model is also suitable for scene generating programs that give pilots fly-through and target previews. The atmospheric effects of the wake model use the well known MODTRAN code, and the radiance calculations use the same methods as the SeaRad water background code currently in TAWS. These basic modeling methods are discussed and results comparing TAWS predictions with radiometric field data are presented. The topic areas include a general wake model description and prediction results for target detection and recognition ranges, zero-range target-with-wake radiance, background radiance, and apparent area.

Keywords: TAWS, SeaRad, validation, atmospheric transmittance, remote sensing, tactical decision aid

1. INTRODUCTION

1.1 Background

The Target Acquisition Weapons Software (TAWS)[1] is a mission planning tactical decision aid. TAWS predicts the performance of selected sensors given the weather forecasts and targeting scenarios. TAWS will calculate detection, recognition, identification, and lock-on ranges for sensors in the mid and far infrared, visible, and laser wavebands. TAWS was developed by the U.S. Air Force for air-to-ground sensor performance predictions. The U.S. Army, Navy, and Coast Guard have adopted TAWS as a component of their mission planning systems and are making changes to TAWS to meet the particular needs of each service. The Navy is adding marine targets and upgrading the water background models. These modifications include accounting for the effects of the ship wake. This report discusses the validation of the ship wake model using a long wave infrared sensor. It does not cover the visible TV sensors, low-light night vision goggles, laser designators, or midwave focal plane array sensors.

1.2 TAWS Modules

TAWS can be grouped into three primary modules according to predictive output: a target-background contrast model, an atmospheric transmission model, and a sensor performance model. These three predictive models are controlled by a graphical user interface (GUI) that also provides the inputs and displays the outputs. The sensor is usually an airborne sensor with an air-to-ground view. The target is viewed in contrast to the surrounding background and this signal is altered by the transmittance and refractive effects of the intervening atmosphere between the target and the sensor. Figure 1 pictorially depicts the role of each of these modules.

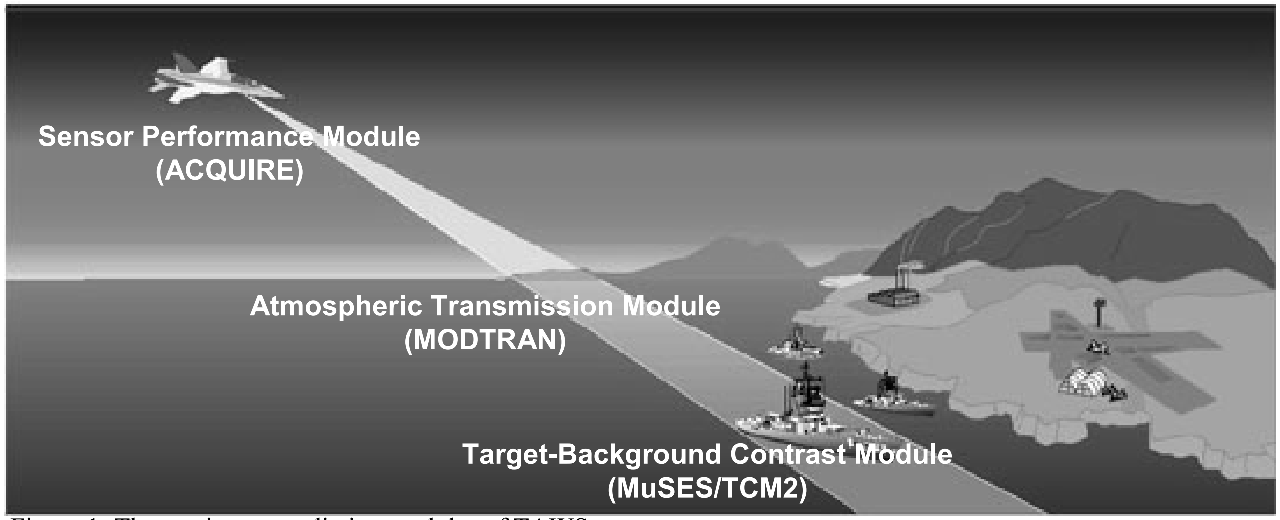


Figure 1: Three primary predictive modules of TAWS.

1.2.1 The Sensor Performance Module

The sensor performance prediction module in TAWS is the ACQUIRE[2] model that was developed by the U.S. Army CECOM Night Vision and Electronics Sensors Directorate (NVESD). The sensor performance model is not directly evaluated in this paper. However, the integrity of the sensor performance model can be ascertained indirectly by comparing overall detection range predictions to measured data. The data in this report were analyzed using the "User Defined Sensor" feature in TAWS to create a sensor model for the AGEMA 900 series calibrated infrared imager.

1.3.1 The Atmospheric Transmission Module

The atmospheric transmission module in TAWS uses a set of subroutines from MODTRAN[3] version 3.5. For the sake of runtime efficiency, the atmospheric transmittance is calculated only once with MODTRAN for a given weather forecast and location. MODTRAN is run at a standard range of four kilometers and then all other ranges are calculated using the Beer's Law relationship. The current version of TAWS uses a two layer atmosphere. But because of wider availability of detailed forecasts for the upper atmosphere, a multi-layer version of the code is planned for TAWS version 4.0. Also, a capability is being to use external extinction profiles from other models, such as, the NRL Aerosol Analysis and Prediction System (NAAPS)[4]. To validate the transmission module, we need to determine the actual transmittance at four kilometers and then compare with the calculated value from TAWS.

1.4.1 The Target-Background Contrast Module

Two target-contrast models are presently employed in TAWS: Thermal Contrast Model 2 (TCM2)[5] and the Multi-Service Electro-optical Signature Software (MuSES)[6]. MuSES is a more recent model using more rigor than its predecessor, TCM2. Both models start with a wireframe geometric representation of the target. Each enclosed area within the wireframe netting becomes a thermal node when material and thermal properties are added to the geometric representation. Each node thermally interacts through conduction, convection, and radiation with adjacent nodes and the surrounding atmosphere and background. TCM2 provides a one dimensional nodal solution between adjacent nodes while MuSES offers a three dimensional thermal solution. The number of facets making up a target can range from around 100 to several thousand. The runtime increases dramatically as the target complexity is increased. For detection range calculations, the primary outputs needed from TCM2 and MuSES are the total apparent area and the equivalent blackbody target-background radiance contrast. Therefore the target and background must be modeled with just enough geometric complexity to accurately determine the radiance contrast and apparent area.

To validate the target-background contrast module in the marine environment, we must measure the equivalent blackbody radiance over the apparent area of the target at the view angle of interest, and we also must measure the equivalent blackbody radiance of the surrounding ocean background. The measured radiances are then converted to equivalent blackbody temperatures and compared with the model predictions. Previous tests[7] have shown the water background model required more detail. To provide the needed rigor for the water background model, an upgraded version of the navy SeaRad[8] model is used in MuSES in place of the original semi-empirical water model of TCM2. SeaRad provides a more rigorous solution and includes compensation for sun glint, clutter, and cloud shadowing effects. Besides being the water background model for MuSES applications in TAWS, SeaRad also provides the basis for radiance calculations for the near field target wake models that are new in TAWS version 4.0. The wake effects affect the detection range of a ship or boat target by increasing the apparent area that contrasts with the water background, changing the appearance of the scene, and changing the total integrated radiance of the contrasting area.

1.4.2 Correcting the Marine Targets for Wake Effects

The hydrodynamics portion of the wake effect is determined using a semi-empirical approach. A basic physics-based model is scaled to a combination of empirical measurements and results from high performance computing (HPC) computational fluid dynamics (CFD) hydrodynamics models, including Havelock-Dawson, Comet, FASTWAKE, and Das Boot[9]. The three primary wave features: Kelvin wake, bow and transom stern breakwater wake, and turbulent centerline wake are each represented by the new wake model. Figure 2 gives a pictorial view of the main wake components that are accounted for in the model.

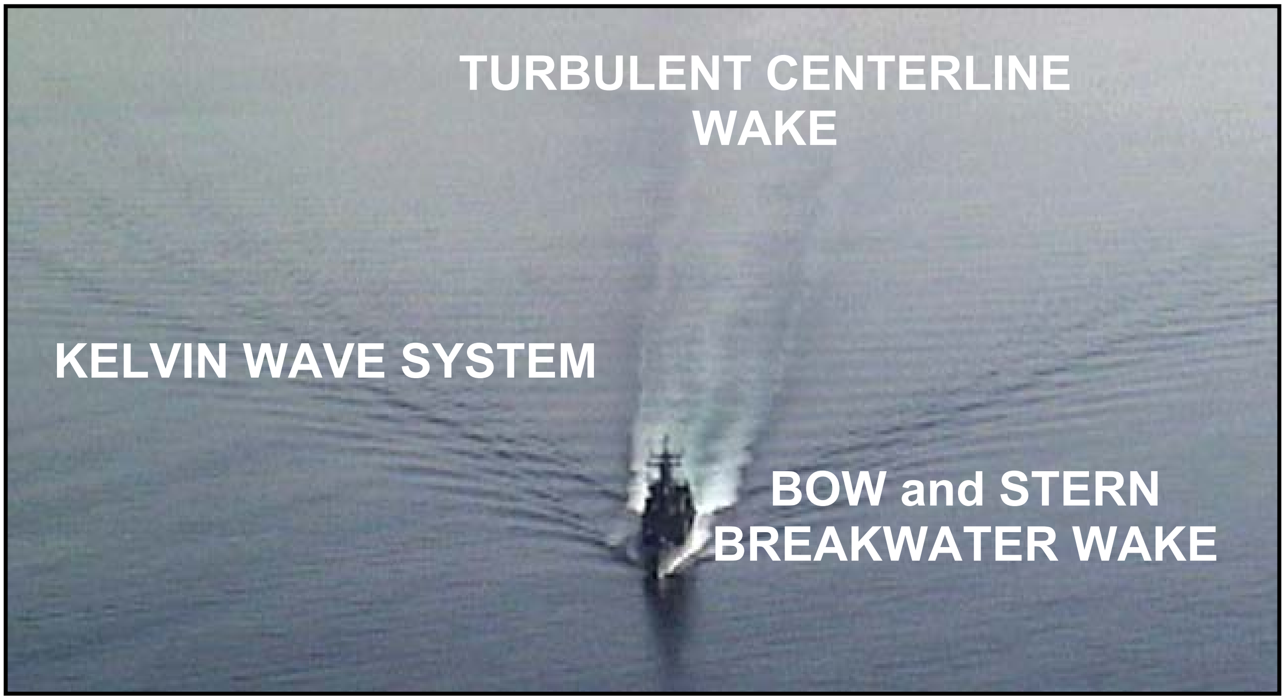


Figure 2: Primary Wake Components Modeled in TAWS.

Planing hull wakes are more complex and are modeled differently than for the displacement hull vessels. So, there are really two wake models in MuSES/TAWS, one for displacement mode and one for planing mode. Typically, the planing hull boats, such as the Boghammar high speed patrol boat, are modeled at representative operating states: off, idle, eight knots (displacement mode), 25 knots (low speed), 35 knots (medium speed), and 50 knots (high speed). The wake state most representative of the ship speed entered by the TAWS user is used in the target radiance calculation for a given TAWS prediction. The extent of the area of the wake field to be applied to the detection range calculation in TAWS is determined by a gridded area in the model that is user-adjustable by changing preset dimensions in the data file corresponding to the wake-enabled target.

After the wake surface topographic features are known from the hydrodynamics modeling, the radiance contributions from the wake and reflective atmosphere must be calculated. The radiance contribution from the reflected atmosphere is determined by the SeaRad code, based on the wake facet distribution and relative whitewater content. A more detailed description of the algorithms and approach to the wake model and its operation in MuSES and TAWS is available in the various reports by the model developers, Coke, et al.[10, 11, 12]

2. VALIDATING TAWS WAKE MODEL APPLICATIONS

2.1 Validation Approach

TAWS primarily provides detection range predictions. However, we cannot evaluate the performance accuracy of the individual models within TAWS from range predictions alone. This is because offsetting errors can cancel each other and sometimes give deceptively accurate results. The target, background, transmittance, and sensor models must each be evaluated on their own merit. This paper will evaluate the target and background radiance predictions for MuSES over-water targets that have wake effects included in the model. We will also present a case study of the MODTRAN atmospheric transmission model as implemented in TAWS. Finally, we will compare overall detection range predictions from TAWS to measured data. The approach will provide as sense of the overall accuracy of TAWS as well as the individual module performance.

The primary field instrument we used for obtaining the radiance of the target and background is the FLIR Systems Incorporated, AGEMA 900 Thermovision dual-wavelength thermal imaging system. The measurement platform for the AGEMA is a twin-engine Piper Navajo, modified with a removable side window. The AGEMA data are supplemented with complete meteorological and navigation data. Several images at a variety of view angles are collected while flying the aircraft around the target. The images are analyzed and corrected for atmospheric influence using the measured meteorological parameters and the MODTRAN code. The zero-range target and background equivalent blackbody temperatures are determined over the total apparent areas and compared with TAWS model predictions.

The theoretical basis for evaluation is based on relationships given by equation (1). The total radiance of a pixel area measured by the AGEMA sensor is given by the left-side of equation (1), where $F(\lambda)$ is the spectral response of the AGEMA, and $W(T_A, \lambda)$ is Planck's spectral radiant emittance at apparent temperature T and wavelength λ. The terms on the right side define how the various target, background and atmospheric radiance components combine to give the total radiant energy received by the AGEMA detector.

$$\frac{1}{\pi}\int_{\lambda_1}^{\lambda_2} W(T_A,\lambda)F(\lambda)d\lambda = \int_{\lambda_1}^{\lambda_2}\varepsilon(\lambda,\theta)_{TARGET}\ \tau(\lambda,R)\left(\frac{1}{\pi}\right)W(T_{TARGET},\lambda)F(\lambda)d\lambda + \int_{\lambda_1}^{\lambda_2}(1-\varepsilon(\lambda,\theta)_{TARGET})\tau(\lambda,R)\left(\frac{1}{\pi}\right)N(\lambda)_{REFLECTED}\ F(\lambda)d\lambda + \int_{\lambda_1}^{\lambda_2}N(\lambda,R)_{PATH}\ F(\lambda)d\lambda \quad (1)$$

The first-term in the right-hand side of the equation is the total integrated radiance of the target or pixel area at zero-range, where T_{TARGET} is target temperature at range $R=0$, $\varepsilon(\lambda,\theta)_{TARGET}$ is the spectral emissivity of the target at zenith angle θ, and $\tau(\lambda,R)$ is the spectral atmospheric transmittance at a range R. The second integral term describes the radiance from surroundings that is reflected off the target toward the sensor. The third term on the right-hand side, $N_{PATH}(\lambda,R)$ is the spectral radiance along the path between the target and the sensor. Although not indicated in the equation, the emissivity of the target in TAWS is assumed to be that of graybody at a temperature integrated over the view area. This can be a source of error for some targets because assuming a constant emissivity over wavelength does not necessarily hold true, especially in the midwave IR band.

An equation similar to equation (1) describes the ocean background surrounding the target area, but the emissivity is further adjusted by the Fresnel reflectance which varies according to the set of facet angles created on the surface of the water by the wind and gravity waves.

2.2 Method Used to Analyze the Calibrated IR Image Data

TAWS predicts the total integrated target radiance and apparent target area before adding the attenuation due to the atmospheric path. To validate the target and background models of the TAWS code, we need to measure the apparent temperature or equivalent blackbody radiance for the wavelengths of interest and also determine the apparent area for the view angle of interest. There is no satisfactory method to measure the zero-range apparent temperature or blackbody radiance directly from onsite point measurements. We must therefore remotely sense the whole target at a distance using a calibrated thermal imager and then correct for the atmospheric influence between the imager and the target. This is also true for the ocean background.

Figure 3, below, shows an example of area analysis on a target ship before correcting for the atmospheric influence. The target area of the ship, the Research Vessel Point Sur in this case, is outlined by the line labeled, AR02. The statistics are shown in the IR-1 Results window. For the target area, AR02, the minimum apparent temperature is 6.3 degrees Celsius, the maximum is 42.0 degrees, the average is 15.83 degrees, the standard deviation is 4.07, and the circumscribed display area is 3209 pixels (of a total viewing area of 136 x 272 = 36992 pixels). Likewise, a representative patch of the background is outlined in the rectangle of AR01. The average apparent temperature of the background in AR01 is 6.13 degrees Celsius. The area labeled AR03 is a sample of the centerline turbulent wake.

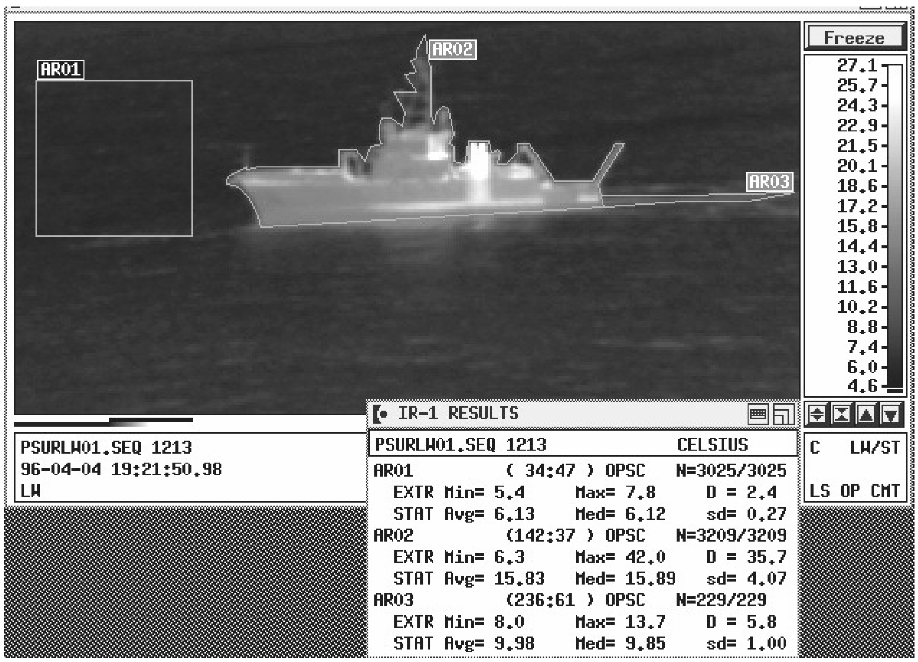


Figure 3: AGEMA image area analysis of background (AR01) and target (AR02).

The initial area analysis yields average apparent temperatures of the target and background that are each treated as an equivalent blackbody radiance needing to be corrected for atmospheric effects. The MODTRAN code corrects for the atmospheric effects between the sensor and the ship target. The surface meteorological data and upper air profiles collected from the aircraft during the imaging flight are used as inputs to MODTRAN. MODTRAN is run in the radiance mode along a slant path as defined by the geometry between the aircraft and the target. The input variable, TBOUND, is varied with iterative runs of MODTRAN until the output matches the full range AGEMA temperature. The TBOUND temperature value that causes the MODTRAN output to match the aircraft AGEMA measurement is equal to the equivalent blackbody temperature that a target would be at zero-range to cause the value indicated at the range of the measurement. This TBOUND temperature value (or equivalent blackbody radiance) is compared to the zero-range prediction from the target-background contrast model in TAWS. The technique works equally well for both the target and the background. In most cases the raw data are collected at such a close range that the correction for the intervening atmosphere is small. Therefore, the error introduced by the MODTRAN correction is also small. The accuracy is primarily determined by the limitations of the AGEMA imager which is specified as plus or minus one percent.

2.3 Background Model: Test Results for the Water/Ocean Background Model, SeaRad

We employed the analysis process described above for several hundreds of images and over a variety of meteorological conditions. As an example, consider the scatter diagrams in Figure 4 that were described in more detail in a previous paper[13]. The two graphs both compare the ocean background radiance of a dataset collected during clear sky conditions off the Santa Barbara coast with TAWS predictions. In this case, the error from the newer SeaRad model in MuSES is atypically similar to the older model in TCM2. However, the error from the newer ocean radiance model, SeaRad is significantly reduced when a more accurate upper air profile is included. This is shown in the plot on the right where the MuSES background predictions fall within the ten percent error lines. As a result of these findings, starting with TAWS version 4.0, a multi-layer upper air atmospheric profile forecast will replace the current two-layer version.

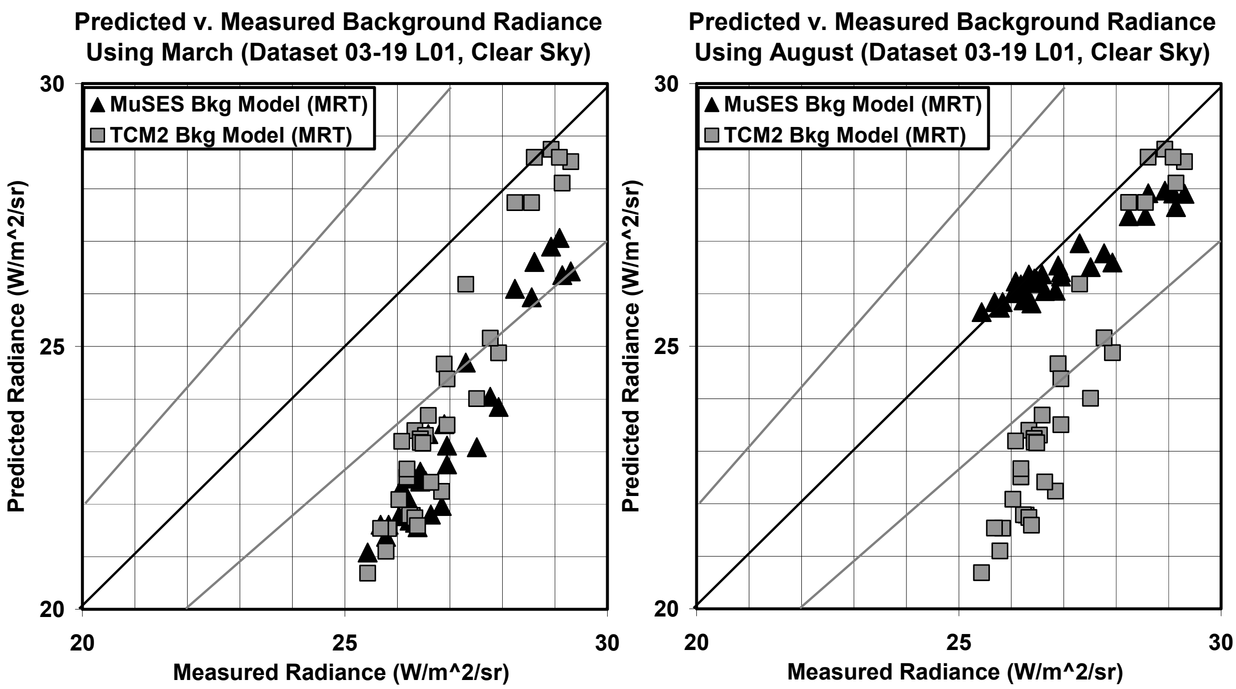


Figure 4: Comparison of predicted and measured zero-range background radiance. The plot on the left shows the results of running TAWS with the correct month, March, and the plot on the right is from running TAWS with August. Running the summer month changed the default upper layer from mid-latitude winter to summer, which was more representative of the actual temperature profile and produced more accurate predictions.

It is important that the water background model, SeaRad, produce accurate results because the same model is also used to determine the radiance of the wake component of the target. When the atmosphere was properly characterized, the SeaRad ocean background model in MuSES produced accurate test results in our case study. The average errors for eight different datasets are shown graphically in Figure 5 where the SeaRad results are compared with the less accurate semi-empirical predecessor model used in TCM2. The TCM2 ocean background produced its greatest error (over 15 percent) with the clear sky twilight case of 19 March while the MuSES SeaRad model stayed below six percent. Typically, errors were within five percent with the MuSES SeaRad model regardless of whether the MRT or MDT method was used. The average error was 10.2 percent over all cases with the older TCM2 empirical background and only 2.7 percent with the newer SeaRad background in MuSES.

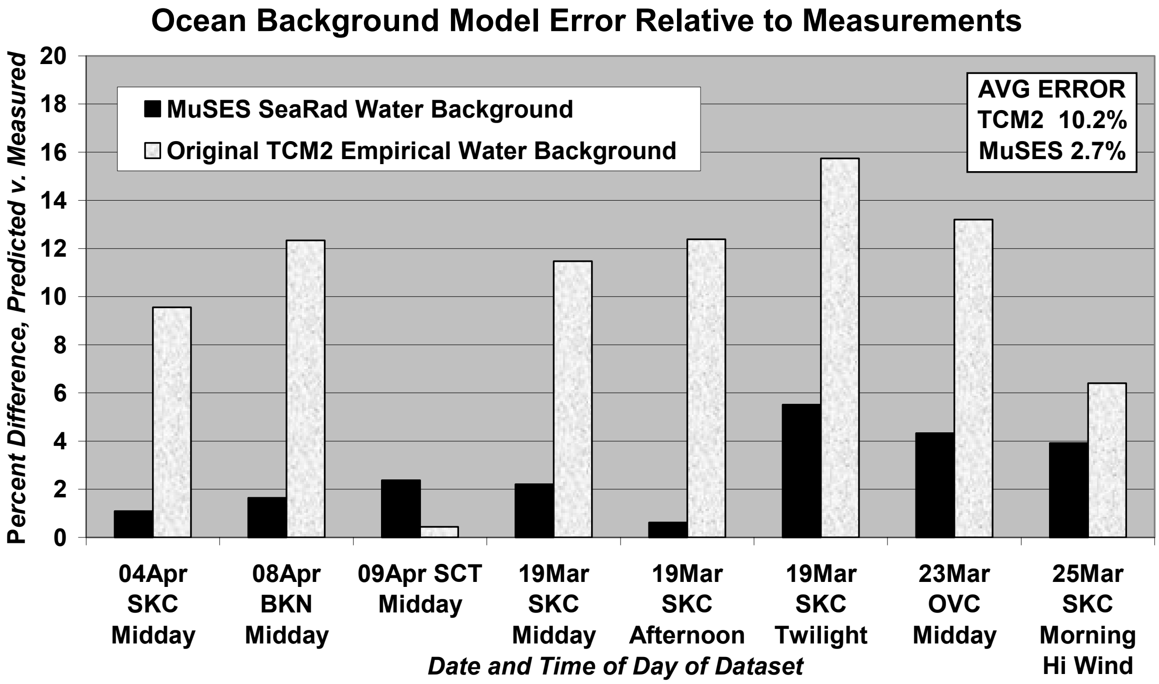


Figure 5: Average percent difference between predicted and measured water background radiance values.

2.4 Target Model: Test Results for Wake-enabled Targets

Evaluation of the target model is similar to that of the background. The measured equivalent blackbody target radiances at zero range are compared with the predictions from TAWS. There presently are three wake-enabled targets in TAWS. They are the 24 foot "go-fast" powerboat, 43 foot Boghammar high speed patrol boat and the 135 foot Research Vessel Point Sur. The Point Sur presents a displacement-hull wake while the powerboat and Boghammar are planing-hull boats. A full set of data are available for the Point Sur. Having insufficient data for the powerboat or the Boghammar, we will make some comparisons with other planing hull boats of similar construction to show that the target radiance values produced by the model are reasonable.

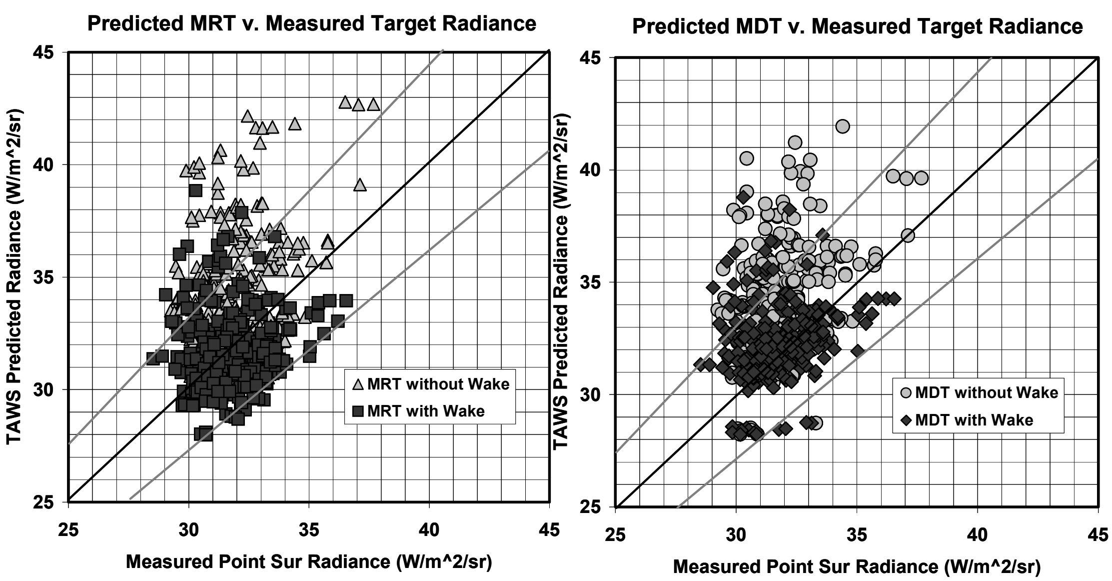


Figure 6: Comparison of MRT and MDT predicted and measured ship radiance with and without wake effects.

Figure 6 is a comparison of measured and predicted target temperatures for several data sets for the Point Sur. The data cover 296 measurements over a wide variety of weather conditions. The results are similar for both the Minimum Resolvable Temperature (MRT) and Minimum Detectable Temperature (MDT) methods of target discrimination. In both cases, the accuracy was improved by adding wake effects. The average MRT error relative to the measured values is 9.1% without wake effects and 4.9% when wake effects are taken into account. The improvement from accounting for the wake is better than expected, given that the wake contribution is relatively small compared to the radiance from the hull and superstructure of the ship for these depression angles that ranged from zero to twenty degrees below the horizon. Obviously, the relative effect of wake on detection is much greater with the planing hull boats that have a much larger wake area and a smaller ship size.

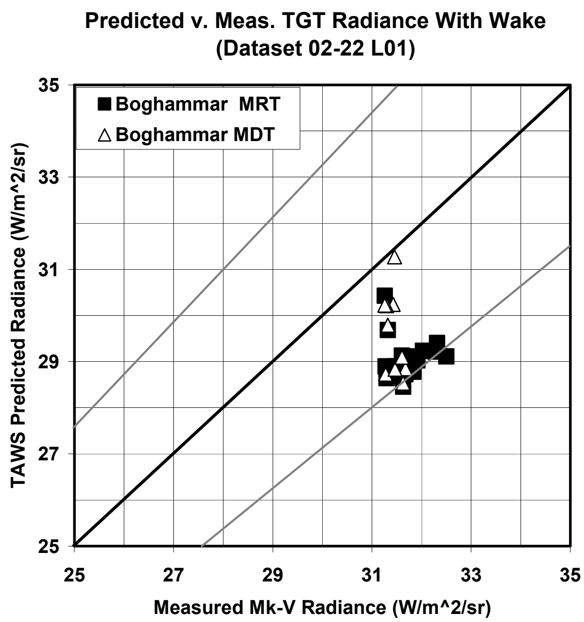


Figure 7: Comparison of predicted and measured ship radiance for a planing hull boat.

For the planing hull boats we compare calibrated image data collected on the 82 foot Mark-V high speed patrol boat and compare with predictions from TAWS for the 43 foot Boghammar. Both boats are aluminum hull construction of similar shape, differing primarily in scale. While the detection range would typically be longer for the Mark-V because of the larger apparent area, the target radiance and background contrast values should be similar for both boats when operating under the same conditions. Figure 7 shows the results of measured Mk-V radiance compared to predictions for the Boghammar. The average error compared to measured values is 8.4 percent using the MRT radiance method, and 5.9 using the MDT method. The graph shows the data falls within the ten percent error bars with a tendency to under-predict the target plus wake radiance. This tendency can easily be corrected by fine tuning the amount of wake area to be included in the calculations. However, it would be best to wait until a larger dataset covering a variety of conditions is available before seriously attempting to fine tune the model.

2.5 Test Results for the Atmospheric Transmittance Model

During some field measurement exercises we were able to collect image data at several distances from the ship or target along the same slant path. This allows us to evaluate the transmittance along that path using the technique reported in a previous paper.[13] We plot the measured target-background contrast temperatures with an exponential least squares fit through the data points. From the resulting equation we can infer the atmospheric transmittance from the exponential and the zero-range target-background temperature contrast from the y-intercept. As an example, the case shown in Figure 8 shows the zero-range contrast temperature difference is 10.34 degrees Kelvin. The contrast temperature difference, measured using a close-up image, is 11.0 degrees Kelvin, a difference of 0.66 degrees using the same imaging device.

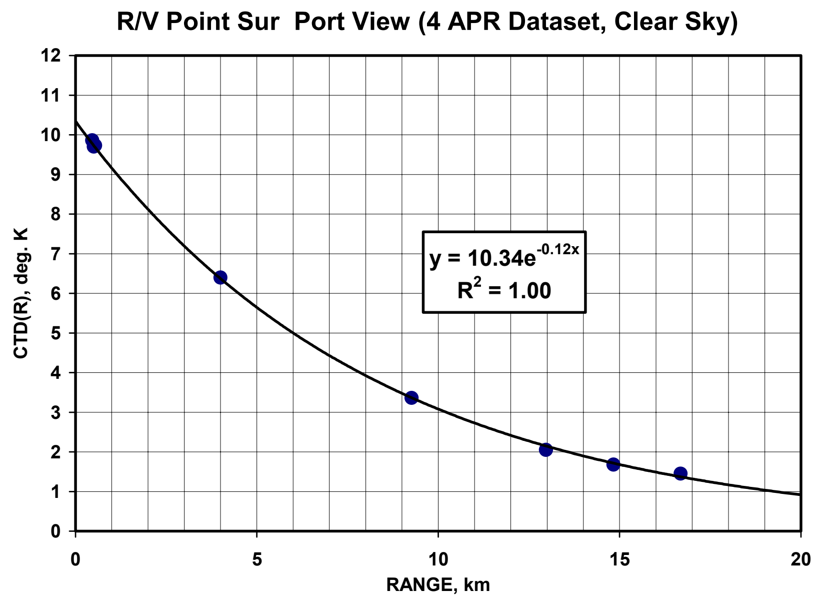
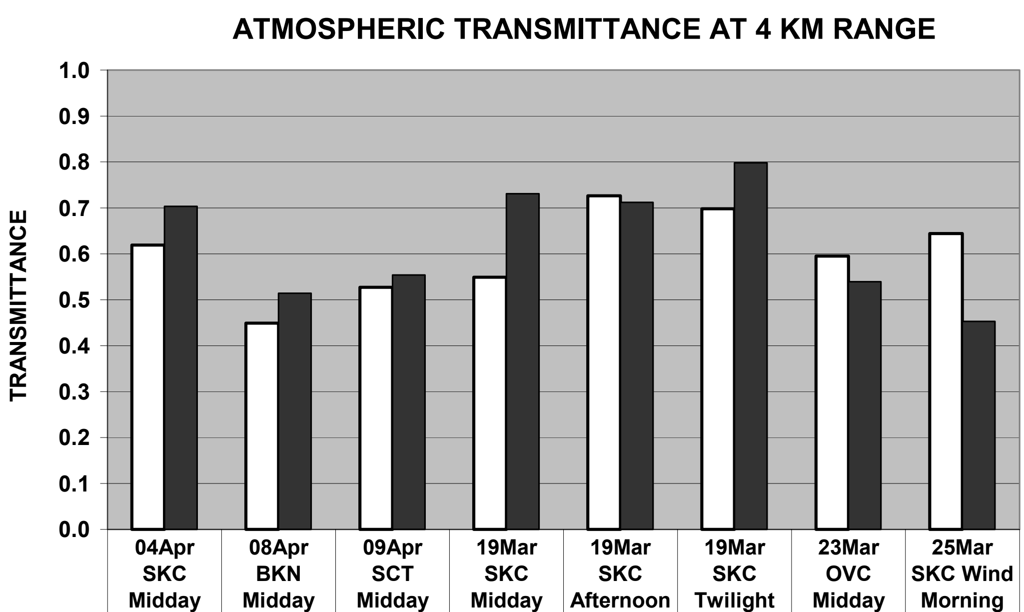


Figure 8: Target-background apparent contrast temperature difference of the R/V Point Sur, port view, as a function of range, with an exponential curve fit. The Y-intercept gives "zero-range" temperature difference. The atmospheric transmittance can be derived from the exponential formula.



	04Apr SKC Midday	08Apr BKN Midday	09Apr SCT Midday	19Mar SKC Midday	19Mar SKC Afternoon	19Mar SKC Twilight	23Mar OVC Midday	25Mar SKC Wind Morning
MEAS TRANS	0.62	0.45	0.53	0.55	0.73	0.70	0.60	0.64
TAWS TRANS	0.70	0.51	0.55	0.73	0.71	0.80	0.54	0.45

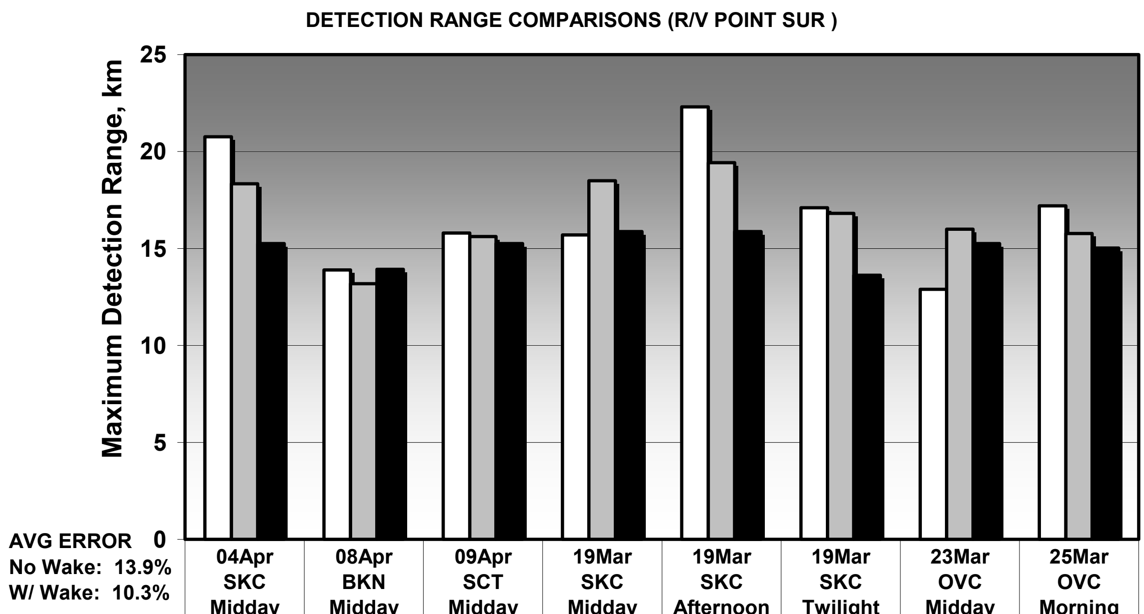
Figure 9: Inferred atmospheric transmittance at a range of four kilometers compared with predictions from TAWS.

Since TAWS calculates the transmittance at a standard range of four kilometers, we can estimate this transmittance by letting x=4 in the exponential equation and ignoring the coefficient. In this case $e^{-0.48}$= 0.619. The predicted transmittance from TAWS for the 4 April case was 0.707 using the Navy Maritime aerosol model with the "intermediate light wind" setting, an over-prediction of 14 percent. However, when an "open ocean light wind" setting was used for the aerosol model, TAWS calculated a transmittance of 0.534, an under-prediction of 13.7 percent. This difference could likely be reduced by adding more atmospheric layers and a better aerosol model to TAWS.

Figure 9 shows a comparison of the TAWS predicted transmittance and the calculated transmittance using the slant path exponential fit to measured values. On average TAWS predictions were within nine percent of the values inferred from the measurements in the eight cases tested. This translates to an average error of 15 percent. As mentioned above, the error could likely be improved by adding more vertical structure and a better aerosol model. The current Navy Aerosol Model is very sensitive to the air mass and visibility parameters which are difficult to accurately determine[14].

2.6 Detection Range Validation

The predictive models in TAWS need to be evaluated individually to see how well each segment performs. But the end user is interested in the end result, range predictions. A previous detection range evaluation using these data produced inconclusive and questionable results.[13] The cause of the variation was determined to be the user-defined sensor parameters that were entered into TAWS for the AGEMA sensor. We have since measured the MRT and MDT response of the AGEMA in the laboratory and applied the new values to the data. The results of running TAWS with the correct sensor parameters are depicted in Figure 10. Figure 10 shows the accuracy and variability of the TAWS detection range predictions for the displacement hull ship, the Point Sur, both with and without the wake model. The overall average detection range error was reduced from 13.9 percent to 10.3 percent by accounting for wake effects.



	04Apr SKC Midday	08Apr BKN Midday	09Apr SCT Midday	19Mar SKC Midday	19Mar SKC Afternoon	19Mar SKC Twilight	23Mar OVC Midday	25Mar OVC Morning
Measured	20.8	13.9	15.8	15.7	22.3	17.1	12.9	17.2
Rng With Wake	18.3	13.2	15.6	18.5	19.4	16.8	16.0	15.8
Rng W/O Wake	15.2	13.9	15.2	15.9	15.9	13.6	15.2	15.0

MEASUREMENT SEQUENCE

Figure 10: Comparison of predicted and observed detection ranges. Shown are the TAWS predictions using the Minimum Detectible Temperature contrast (MDT) method and the Minimum Resolvable Temperature contrast (MRT) method with the observed detection ranges using the airborne AGEMA 900 longwave sensor.

The improvement will be notably greater for the high speed planing hull boats. This is because the wake of these high speed boats has an order of magnitude greater contribution to the target-background contrast than for the Point Sur. Our measurements have shown about a 3.6 percent change in target radiance when wake effects are added to the Point Sur, while there was about a 34.8 percent change in the planing hull boat radiance when the wake is considered.

Since detection range calculations depend on both the target-background contrast at the sensor and apparent area of the target, we also verified correct operation of the apparent area calculations in TAWS. Because there is some subjectivity and inherent error determining target size from the pixels of the image data, quantitative results are not presented. Instead, we note that the comparisons indicate correct performance of model for both the wake and the target, showing values matching the same range as the image data.

Version 4.0 of TAWS will include recognition and identification ranges along with detection and lock-on ranges that were included in previous versions. There is ongoing work with the Coast Guard to evaluate range predictions for high speed boats using TAWS and field data collected in the Florida Keys. There is some difference in the definitions of the range points between the Coast Guard and TAWS (e.g., evaluation and classification ranges v. recognition and identification ranges) that will complicate the validation process.

3. CONCLUSION

4.1 Summary of Results

The water background model in TAWS performed well when using the SeaRad model in MuSES, giving an average error of only 2.7 percent. However, one case was presented to show that it is important to input an accurate atmospheric profile for SeaRad to be able to correctly calculate the reflected sky component of the sea surface radiance. The capability of inputting multiple atmospheric layers into MODTRAN will be included in TAWS version 4.0. The multilayer input may also improve the accuracy of the atmospheric transmittance predictions.

The target models in TAWS that included wake effects also performed well. We compared radiance predictions with measured data and checked proper operation of the apparent area calculations. The average overall error was reduced from 9.1 to 4.9 percent when the displacement hull wake model was compared to the Point Sur model without including the wake effects. The large amount of data available for the Point Sur gives us confidence in the displacement hull wake model performance. The planing hull wake model also performed well, but more high speed boat data, collected under a variety of weather conditions, is needed for a more thorough evaluation of the planing hull model.

The atmospheric transmission model is sensitive to air mass and visibility inputs when using the Navy Aerosol Model and would likely benefit from better modeling of the vertical structure of the atmosphere. The average error for the current two-layer model is 15 percent for these data. Future enhancements of atmospheric layering and direct input of extinction profiles should reduce the error.

The detection range predictions also benefited from the wake model. Average error dropped from 13.9 to 10.3 percent when the wake model was employed in the target-background calculations for the displacement hull target. No detection range data were available for the planing hull targets, such as the 24 foot speed boat and the 43 foot high speed patrol boat.

4. FUTURE PLANS and CAPABILITIES

4.1 Far Wake Detection Capability

Early detection can be greatly improved if the late were included as a target in TAWS. Ships leave a track that appears as a slick in the water. This ship track can persist for several tens of minutes under the right conditions. The late wake ship track will quickly lead a pilot right to the target. It would be a valuable addition to TAWS if it could predict the magnitude, persistence and best view altitude of a ship track for a particular ship size of interest.

The primary conditions that need to be considered and input into TAWS have already been studied in a recent feasibility study.[15] The study concluded that the far wake persistence depends primarily on the amount of water displaced (primarily a ship displacement driven parameter), the wind velocity, sea state, surfactant concentration, and thermal gradient of the near-surface water. We have since begun developing a hydrodynamics model for a 4100 ton displacement frigate and a 9100 ton destroyer. We expect to add a radiance prediction capability to the hydrodynamics model in fiscal year 2004. Additionally, far wake data that can possibly test and validate the model is being collected in conjunction with another field test under the CBLAST program by investigators from the Applied Physics Laboratory at the University of Washington and Woods Hole Oceanographic Institution in Massachusetts. We are working to make the far wake ship track detection feature available in TAWS in 2005.

4.2 Adding and Validating New Targets and New Sensor Performance Parameters

Three additional wake-modeled targets are being added to TAWS. These are a destroyer based on the 563 foot DD-963, and two Special Operations Command (SOC) SEAL Team Boats: a 36 foot rigid-hull inflatable boat (RIB), and an 82 foot Mark-V high speed patrol boat. The SEAL team will test the utility of TAWS for detection and vulnerability assessment for interdiction missions. TAWS can provide the time of day when detection is least and most likely, best direction of approach, and safe distance information. We worked with the SEAL team before the Iraq war to collect data on the RIB and Mark-V which will help validate the models. Besides the new ship models, TAWS 4.0 will provide recognition and identification range predictions. These new targets and features should make TAWS more useful for navy marine mission planning.

4.3 Upward and Horizontal Line of Sight (ULOS and HLOS)

The addition of SEAL team boat targets will provide a new use for TAWS: vulnerability assessment. Still, the primary use for TAWS is target detection. That means the Army, Marine Corp. and Navy SOC units would find TAWS more useful if detection predictions were available for ground warfare operations. TAWS was originally designed for air-to-ground strike warfare mission planning. To handle ground-to-ground and ground-to-air scenarios requires new research and significant design changes to the background and target models. The first and most obvious change is to add a sky background to TAWS.

The Army Research Laboratory has taken the lead by providing a new sky background model for TAWS using their Sky-to-Ground Ratio (SGR) program. An Army test version of TAWS can now predict detection ranges of an upward-viewing ground sensor detecting helicopter targets against a sky background using the new SGR model. Further research and work are needed to extend the ULOS capability to near-horizon, HLOS, and ground-to-ground aspect angles.

Another sky background model competing with SGR is available for TAWS from MuSES. The MuSES sky model is based on the same MODTRAN atmospheric code that computes the reflected sky component of the water background and wake models. We are currently modifying this model to handle mixed sky and coastal land backgrounds in the marine environment. The navy opted to use this model because it is already being used for over-water calculations in TAWS. If it is decided to unify under the army SGR sky model, major modifications to MuSES will be needed to make SeaRad and the new wake models compatible with SGR. For the time being, no one has the resources to identify and solve all the near-horizon, sky, terrain elevation effects, and mixed backgrounds and other problems associated with a true HLOS capability. So, stepwise improvements are being made as resources become available.

4.4 Speed Upgrades – MuSES Patches with 1-D Solver

Interestingly, as previously reported[13], the older TCM2 target prediction model produces nearly as accurate results as the newer MuSES model and at a much higher speed. However, the wake model and improved ocean background model are not compatible TCM2. Also, TCM2 is no longer supported by ThermoAnalytics. However, MuSES has a potential capability of condensing target detail of complex multi-faceted targets, and MuSES can also be modified to make one dimensional inter-nodal solutions like its predecessor, TCM2. Employing these two techniques in MuSES should greatly reduce runtimes. This modification is planned for testing in TAWS version 4. The more targets and time intervals that a TAWS user runs, the greater the runtime. When the ocean background and wake calculations are added to the mix, runtimes can become intolerable. Therefore, these runtime reduction measures are a welcome improvement for heavy users of TAWS.

4.5 Upgrade Water Background Model in the Visible Waveband

The runtime of the SeaRad model is acceptable in the IR, but it would take too long in the visible waveband. A sky model other than MODTRAN is needed to speed up the process. Some work has been done in this area and the army SGR model may be suitable for a water background model in the visible waveband, but work still needs to be proposed and implemented in this area.

4.6 Atmospheric and Oceanographic Profiles

As mentioned previously, TAWS 4.0 will address the need to input an atmospheric profile prediction into TAWS. This should improve the accuracy of the water background, wake, and atmospheric transmission models. However, as a future task, it would be good to validate the new upper layer profiles capability in TAWS with field data.

4.7 Aerosol Continuity Using Direct Input and Remote Sensing Possibilities for Into TAWS

Future improvements to TAWS should focus on replacing the model calculations with direct inputs from either predetermined values obtained from numerical weather models or through satellite remote sensing products. Direct input can bypass some models in TAWS, relieving TAWS of the burden of time consuming calculations, and perhaps providing better accuracy. The atmospheric transmission model is the best candidate for replacing the model with direct input from remote sensing products. Several new products that combine remote sensing with predictive models are becoming available. One example is the NRL Aerosol Analysis and Prediction System (NAAPS)[4] that is able to predict advection of aerosols due to smoke. NAAPS may also be able to provide an extinction profile for TAWS. The advantage of direct input from remote sensing is that it reduces the need for input parameters to run the MODTRAN model and improves runtime efficiency.

ACKNOWLEDGEMENTS

This work was supported by the Office of Naval Research Code 322 and the Space and Naval Warfare Systems Command PMW-155. Thanks to those who helped collect and process these data, Raymond Turner and Lee Harding of the San Diego State Foundation.

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